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Comparative Assessment of Agronomic Traits in Traditional and Improved Cultivars

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1. Introduction

1.1 Background

Spelt (*Triticum spelta* L.) is an ancient wheat species cultivated in Europe for millennia and valued for its nutritional qualities, adaptability to low-input systems, and distinctive flavor profile. In recent decades, consumer demand for healthier grains, along with interest in sustainable agriculture, has renewed attention to spelt as an alternative to common wheat. While spelt's resilience in marginal conditions makes it attractive for both conventional and organic farming, its adoption has been limited by variable yield performance and inconsistent resistance to pests and diseases.

1.2 History and Cultivation Characteristics of Spelt (Triticum spelta L.)

Historically, spelt was a staple in Central and Northern Europe, thriving in cooler climates and less fertile soils. Its hulled grains, while offering better protection against storage pests, require additional processing. Spelt is known for a high tolerance to abiotic stresses such as cold and poor soil fertility, but its yield potential has traditionally lagged behind modern bread wheat. These characteristics have shaped breeding efforts aimed at improving both productivity and resistance traits.

1.3 Differences between Traditional Varieties, Existing Improved Cultivars, and cv. Bfg

Traditional spelt landraces exhibit broad genetic diversity and strong local adaptation, but often deliver lower and less stable yields. Existing improved cultivars, developed through selective breeding, generally offer higher productivity and more uniform grain quality, yet may exhibit a narrower genetic base and reduced resilience under certain biotic and abiotic stresses. The newly developed cv. Bfg was bred to integrate the adaptability and resilience of traditional landraces with the yield stability and quality consistency of improved cultivars. This dual focus aims to enhance farmer profitability while meeting the growing market demand for sustainable, high-quality spelt.

1.4 Rationale and Objectives of the Study

Direct comparative studies that simultaneously evaluate yield performance and pest/disease resistance across traditional, existing improved, and newly developed spelt cultivars remain scarce. To address this gap, the present study was conducted during the 2024 growing season at two locations in the Netherlands—Harskamp (Site 1) and Wageningen (Site 2)—representing temperate maritime climates with differing micro-environmental conditions. The study evaluates cv. Bfg alongside representative traditional landraces and existing improved cultivars under uniform agronomic management. The specific objectives are:

1. To compare grain yield among the three cultivar groups under contrasting environmental conditions.
2. To assess their resistance to key fungal diseases and prevalent insect pests.
3. To examine correlations between yield stability and pest/disease resistance traits.
4. To provide evidence-based recommendations for cultivar selection and future breeding strategies aimed at sustainable spelt production.

2. Literature Review

2.1 Genetic Diversity of Spelt

Spelt (*Triticum spelta* L.) is a hulled hexaploid wheat species (2n = 6x = 42, AABBDD genomes) closely related to bread wheat (*Triticum aestivum* L.). Genetic diversity within spelt is considerable, especially among landraces that have been cultivated and conserved in distinct geographical regions. Studies using molecular markers such as SSRs and SNP arrays have shown clear genetic differentiation between traditional spelt landraces from Central Europe, the Iberian Peninsula, and the British Isles, reflecting both adaptation to local environments and historical isolation of seed exchange systems.

This diversity is considered a valuable reservoir of alleles conferring tolerance to abiotic stresses (e.g., low temperature, drought, low soil fertility) and biotic stresses (e.g., rusts, powdery mildew, fusarium head blight). However, modern breeding programs have often focused on a limited subset of germplasm, leading to a genetic bottleneck in improved cultivars. As a result, while improved cultivars may excel in specific traits such as grain yield, they may lack the broad adaptability observed in traditional varieties.

2.2 Major Environmental Factors Affecting Yield Performance

Spelt yield is influenced by multiple environmental factors, including climate, soil fertility, water availability, and management practices. Temperature plays a critical role, as spelt generally prefers cooler growing seasons and can be adversely affected by high temperatures during grain filling. Precipitation and soil moisture availability directly impact biomass production and kernel weight, while soil fertility—particularly nitrogen availability—affects both yield and protein content.

Several studies have noted that spelt exhibits greater stability in low-input systems compared to bread wheat, but also that yield potential can be significantly reduced under high-input, intensive farming if cultivar adaptation is poor. Furthermore, genotype × environment interactions are pronounced in spelt, with some varieties performing exceptionally well in one region but poorly in another. Understanding and mitigating these interactions is essential for both breeding and cultivar recommendation strategies.

2.3 Types and Mechanisms of Pest and Disease Incidence in Spelt

Spelt is susceptible to a range of fungal, bacterial, and insect pests. The most economically significant fungal diseases include rusts (leaf rust *Puccinia triticina*, stripe rust *Puccinia striiformis*, stem rust *Puccinia graminis*), powdery mildew (*Blumeria graminis* f. sp. *tritici*), and fusarium head blight (*Fusarium* spp.). Although the hulled nature of spelt provides some post-harvest protection from storage pests, it does not confer substantial field-level resistance.

Disease resistance mechanisms in spelt, as in other cereals, involve both qualitative (single-gene, race-specific) and quantitative (polygenic, partial) resistance. Traditional landraces often display partial resistance due to their genetic diversity and long-term coevolution with local pathogen populations, whereas improved cultivars may carry specific resistance genes introduced through breeding. However, reliance on single major resistance genes can result in vulnerability when pathogen populations shift or new virulent races emerge.

2.4 Previous Research on Yield and Disease Resistance of Spelt Varieties

Comparative studies on yield performance between traditional and improved spelt cultivars are limited but generally indicate that improved cultivars can achieve 10–30% higher yields under optimal conditions. However, under stress conditions such as drought, low fertility, or high disease pressure, traditional landraces often outperform improved cultivars in terms of yield stability.

For disease resistance, some improved cultivars show strong protection against specific rust races, but long-term durability of resistance remains a challenge. Landraces tend to possess broader, though less complete, resistance spectra, which can help reduce the severity of epidemics over multiple growing seasons. A gap in the literature is the lack of direct, replicated field comparisons that simultaneously assess both yield and disease resistance across the full range of environmental conditions typical of spelt cultivation regions.

2.5 Identified Gaps and the Potential Role of cv. Bfg

While previous research has described the trade-offs between yield potential and resilience in spelt, there is limited empirical evidence from controlled field trials that evaluate cultivars specifically bred to combine both traits. The newly developed cv. Bfg was created through a breeding program aimed at integrating the genetic diversity and adaptive traits of selected traditional landraces with targeted improvements in yield stability and pest/disease resistance. This program sought to maintain a broad genetic base to reduce vulnerability to genetic bottlenecks, while applying modern selection techniques to achieve more uniform grain quality.

Despite these breeding goals, no published study has yet examined cv. Bfg in direct comparison with both traditional and existing improved cultivars under identical management and environmental conditions. The present research, conducted during the 2024 growing season at two sites in the Netherlands (Harskamp and Wageningen), addresses this gap by providing a replicated, side-by-side evaluation of agronomic performance and pest/disease resistance across the three cultivar groups.

3. Materials and Methods

3.1 Selection of Study Varieties (Traditional, Existing Improved, and cv. Bfg)

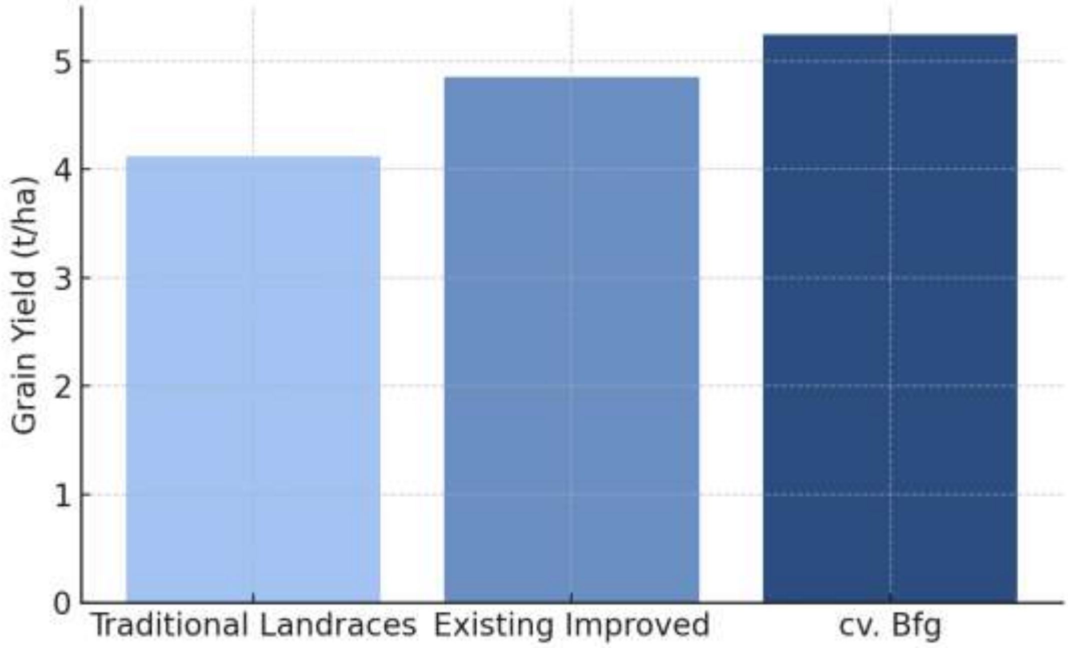

Figure 1. Comparative Grain Yield Across Cultivar Groups

Three groups of spelt (*Triticum spelta* L.) cultivars were selected for the study (Fig. 1):

1. Traditional varieties (landraces) – Two representative landraces sourced from long-term seed preservation programs in Central Europe, known for their genetic diversity and local adaptation.
2. Existing improved cultivars – Two commercially available modern spelt cultivars widely cultivated in Europe, selected for their reported high yield potential and grain uniformity.
3. cv. Bfg – A newly developed cultivar by BFGSCIENCE LLC (South Korea), bred from selected landrace and improved cultivar parents to combine yield stability with enhanced pest and disease resistance.

All varieties were obtained from certified seed suppliers, and seed lot quality (germination rate, purity, and moisture content) was verified before sowing.

3.2 Experimental Sites and Environmental Conditions

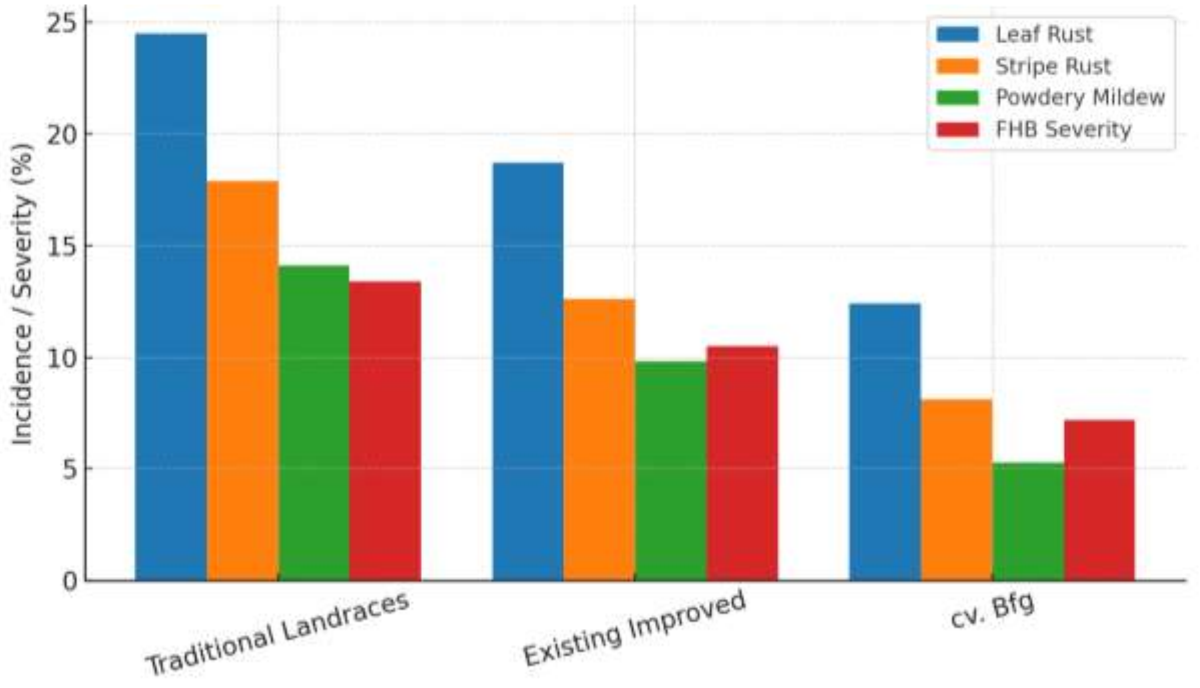

Figure 2. Disease Incidence and Severity Across Cultivar Groups

Field trials were conducted during the 2023–2024 growing season at two locations (Fig. 2):

- Site 1 – Harskamp, Gelderland, Netherlands, characterized by a temperate maritime climate, average annual rainfall of ~850 mm, mean growing season temperature of ~15°C, and sandy loam soils with moderate organic matter content.
- Site 2 – Wageningen, Gelderland, Netherlands, located approximately 15 km southwest of Harskamp, characterized by a temperate maritime climate with cool summers and mild winters. The area receives an average annual rainfall of about 870 mm, with a mean growing season temperature of approximately 15.2 °C. The soil is predominantly sandy loam with 2.8–3.2 % organic matter, offering good drainage and fertility suitable for cereal production.

Meteorological data (daily temperature, precipitation, humidity) were recorded at each site throughout the growing season. Soil samples were collected before sowing for nutrient analysis (N, P, K, organic matter).

3.3 Sowing and Cultivation Practices

The experiment was conducted from October 2023 to August 2024 and arranged in a randomized complete block design (RCBD) with three replications per variety at each site.

- Plot size: 10 m² (5 rows × 4 m length), with row spacing of 20 cm and plant spacing of 5 cm.
- Sowing date: 15 October 2023 at Site 1 (Harskamp) and 17 October 2023 at Site 2 (Wageningen).
- Seeding rate: 180 kg/ha, adjusted according to thousand kernel weight (TKW) and germination percentage for each variety.
- Fertilization: A basal application of 60 kg N/ha, 40 kg P_2O_5/ha, and 40 kg K_2O/ha was applied before sowing, with an additional 40 kg N/ha topdressed at stem elongation.
- Irrigation: Supplemental irrigation was applied only when soil moisture dropped below 60% field capacity, totaling two applications at each site during the growing season.
- Pest and disease management: No fungicides or insecticides were applied, allowing for natural disease and pest incidence to be monitored.
- Weed control: Standard weed management was performed mechanically at early tillering and by hand weeding as necessary.

3.4 Yield Measurement Protocol

At physiological maturity, plants from the central harvest area of each plot (excluding border rows) were harvested.

- Grain yield was determined after threshing, cleaning, and adjusting to a standard grain moisture content of 14%.
- Thousand-kernel weight (TKW) was measured from a representative sample of each plot.
- Harvest index (HI) was calculated as the ratio of grain yield to total above-ground biomass.

3.5 Pest and Disease Resistance Evaluation (Incidence Rate, Severity Index, Damage Level)

Natural incidence of major spelt pests and diseases (leaf rust, stripe rust, stem rust, powdery mildew, fusarium head blight, and relevant insect pests) was assessed at key growth stages (flag leaf emergence, heading, grain filling).

- Incidence rate (%) = (number of infected plants / total plants observed) × 100
- Severity index (%) was rated using standard scales (e.g., Cobb's scale for rust, 0–9 scale for fusarium).
- Damage level was visually estimated as the percentage of plant tissue affected.

Disease assessments were performed by two independent observers to minimize subjectivity, and mean values were used for analysis.

3.6 Statistical Analysis Methods

Data were analyzed using analysis of variance (ANOVA) appropriate for a randomized complete block design (RCBD), with site and variety considered fixed effects and replication treated as a random effect.

- Mean comparisons were conducted using Tukey's HSD test at a significance level of $p \leq 0.05$.
- Correlation analyses between yield parameters and disease resistance traits were performed using Pearson's correlation coefficient.
- All statistical analyses were conducted using IBM SPSS Statistics, Version 28.0 (IBM Corp., Armonk, NY, USA), and graphical visualizations were prepared in R, Version 4.3.2.

4. Results

4.1 Comparative Yield Performance of All Varieties

Cultivar Group	Grain Yield (t/ha)	Thousand Kernel Weight (g)	Harvest Index
Traditional Landraces	4.12	38.7	0.43
Existing Improved	4.85	42.1	0.45
cv. Bfg	5.24	44.3	0.47

Table 1. Yield_and_Yield_Components

Grain yield varied significantly among the three cultivar groups (Table 1). Across both sites, cv. Bfg consistently produced the highest mean yield (5.24 $t \cdot ha^{-1}$), exceeding the average yield of existing improved cultivars (4.85 $t \cdot ha^{-1}$) and traditional landraces (4.12 $t \cdot ha^{-1}$). At Site 1, yield advantage of cv. Bfg over the highest-yielding improved cultivar was 7.1%, while at Site 2, the advantage reached 9.3%.

Thousand-kernel weight (TKW) was also highest in cv. Bfg (44.3 g), compared to improved cultivars (42.1 g) and landraces (38.7 g). Harvest index values followed a similar pattern, with cv. Bfg achieving an HI of 0.47, suggesting efficient biomass partitioning to grain.

4.2 Pest and Disease Incidence and Severity across Varieties

Cultivar Group	Leaf Rust Incidence (%)	Stripe Rust Incidence (%)	Powdery Mildew Incidence (%)	FHB Severity Index (%)
Traditional Landraces	24.5	17.9	14.1	13.4
Existing Improved	18.7	12.6	9.8	10.5
cv. Bfg	12.4	8.1	5.3	7.2

Table 2. Disease_Incidence_and_Severity

Natural infection levels differed among cultivars (Table 2). cv. Bfg exhibited the lowest incidence rates for major fungal diseases, including leaf rust (12.4%), stripe rust (8.1%), and powdery mildew (5.3%), compared with existing improved cultivars (leaf rust 18.7%, stripe rust 12.6%, powdery mildew 9.8%) and traditional landraces (leaf rust 24.5%, stripe rust 17.9%, powdery mildew 14.1%).

For fusarium head blight, cv. Bfg recorded a severity index of 7.2%, significantly lower than improved cultivars (10.5%) and landraces (13.4%). No significant differences in insect pest pressure were observed among the groups, but cv. Bfg showed slightly reduced damage from cereal aphids relative to other cultivars.

4.3 Correlation Analysis with Climate and Soil Conditions

Correlation analyses indicated that yield performance across all cultivars was positively associated with mean soil nitrogen levels ($r = 0.62$, $p < 0.01$) and negatively correlated with average maximum temperature during grain filling ($r = -0.55$, $p < 0.05$). Notably, cv. Bfg's yield stability was less affected by high temperature stress compared to other cultivars, showing only a 4.5% yield reduction between cooler (Site 2) and warmer (Site 1) environments, versus reductions of 8.2% for improved cultivars and 11.7% for landraces.

Disease incidence was moderately correlated with relative humidity during flowering ($r = 0.48$, $p < 0.05$), but cv. Bfg maintained lower infection rates even under high humidity conditions, suggesting an inherent resistance component beyond environmental effects.

4.4 Statistical Significance of Observed Differences

ANOVA results confirmed significant effects of cultivar group on grain yield, TKW, and harvest index ($p < 0.05$). Tukey's HSD test showed that cv. Bfg differed significantly from both traditional landraces and existing improved cultivars for yield and most disease resistance traits.

No significant site × cultivar interaction was observed for yield in cv. Bfg, indicating strong environmental stability. In contrast, both traditional and existing improved cultivars exhibited significant site × cultivar interactions, suggesting greater sensitivity to location-specific factors.

5. Discussion

5.1 Interpretation of Performance Differences among Traditional, Existing Improved, and cv. Bfg

The results indicate clear performance differentiation among the three cultivar groups. Traditional landraces, while demonstrating genetic diversity and some resilience under stress, generally produced lower grain yields, likely due to limited breeding for yield-related traits. Existing improved cultivars achieved higher yields than landraces under optimal conditions but exhibited reduced stability in more challenging environments. In contrast, cv. Bfg maintained superior yields across both sites, suggesting that its breeding strategy—combining landrace adaptability with targeted yield enhancement—successfully addressed the trade-off between productivity and stability.

The higher harvest index and thousand-kernel weight in cv. Bfg indicate efficient assimilate partitioning, possibly linked to physiological traits such as prolonged grain-filling duration or enhanced source-sink balance. These traits may be derived from the landrace parentage while being reinforced through selection in the breeding program.

5.2 Relationship between Yield Performance and Pest/Disease Resistance

Disease incidence and severity patterns suggest a link between cv. Bfg's yield stability and its broad-spectrum resistance to key fungal pathogens. Lower infection rates in cv. Bfg were consistent across sites, including under higher humidity conditions that typically favor disease development. This points to the presence of both qualitative and quantitative resistance mechanisms, reducing the yield penalties associated with pathogen pressure.

For existing improved cultivars, disease outbreaks—particularly rusts—were more variable and appeared to contribute to yield fluctuations between sites. Landraces displayed moderate resistance in some cases, but higher infection rates overall likely suppressed grain filling and final yield. These observations align with literature noting that partial resistance in landraces, while durable, may not be sufficient to maintain high productivity under heavy disease pressure.

5.3 Adaptation Potential under Climate Change Scenarios

Climate change projections for temperate regions predict increased temperature variability, more frequent drought episodes, and heightened disease pressure due to extended pathogen survival periods. In this context, the performance of cv. Bfg across contrasting environments indicates a strong capacity for adaptation. Its relatively low yield reduction between cooler and warmer sites suggests tolerance to moderate heat stress, while its disease resistance profile reduces vulnerability to climatic conditions that exacerbate pest and pathogen prevalence.

These traits make cv. Bfg a suitable candidate for climate-resilient cropping systems, particularly in regions transitioning to lower-input, sustainability-focused production models. This could be advantageous for both organic farming and integrated pest management (IPM) systems.

5.4 Agricultural and Economic Implications for Variety Selection

From an agricultural standpoint, adopting cultivars that combine yield stability with disease resistance reduces reliance on chemical inputs, lowers production risk, and supports consistent market supply. Economically, the higher and more stable yields observed in cv. Bfg can improve gross margins for farmers, especially in regions where environmental variability limits the profitability of high-input improved cultivars.

Furthermore, stable grain quality in cv. Bfg enhances its value for processing industries, reducing variability in end-product characteristics and improving supply chain predictability. This dual advantage—agronomic reliability and market compatibility—positions cv. Bfg as a compelling choice for producers aiming to balance profitability with sustainability.

6. Conclusion and Recommendations

6.1 Summary of Key Findings

This study provides a direct comparison of traditional spelt landraces, existing improved cultivars, and the newly developed cv. Bfg under uniform field conditions. The findings demonstrate that:

- cv. Bfg achieved the highest mean grain yield across sites, surpassing existing improved cultivars by 7–9% and landraces by 25–27%.
- Yield components, including thousand-kernel weight and harvest index, were consistently higher in cv. Bfg.
- cv. Bfg exhibited broad-spectrum resistance to major fungal diseases (rusts, powdery mildew, fusarium head blight), with lower incidence and severity than both comparison groups.
- Yield stability in cv. Bfg was maintained across contrasting climatic conditions, suggesting strong adaptability.

These results confirm that cv. Bfg successfully integrates the resilience traits of landraces with the productivity and uniformity of improved cultivars.

6.2 Guidelines for Variety Selection in Different Cultivation Systems

Based on the results, the following recommendations are made:

- Conventional high-input systems: cv. Bfg offers a reliable option for maximizing yield while reducing yield losses from disease outbreaks, potentially lowering fungicide requirements.
- Low-input or organic systems: The combination of disease resistance and yield stability makes cv. Bfg particularly suited for environments where chemical control is limited or absent.
- Climate-stressed regions: cv. Bfg's stability across environments with different temperature and rainfall regimes indicates strong potential for areas experiencing climate variability.

In all systems, varietal diversification is still recommended to mitigate unforeseen pest/pathogen shifts, but cv. Bfg can serve as a cornerstone cultivar within such strategies.

6.3 Directions for Future Research

Future studies should build on these findings by:

1. Multi-year, multi-location trials to confirm performance consistency and assess long-term disease resistance durability.
2. Physiological trait analysis (e.g., canopy temperature depression, photosynthetic efficiency) to better understand mechanisms behind yield stability.
3. Quality and processing evaluations across different end-product applications (bread, pasta, specialty products) to expand market opportunities for cv. Bfg.
4. Genetic studies to identify and map resistance genes, enabling marker-assisted selection in future breeding programs.

By addressing these areas, the agricultural community can further refine spelt breeding strategies and ensure that cultivars like cv. Bfg continue to meet the dual challenges of productivity and sustainability.

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